Ice Surface Temperature Retrieval from AVHRR, ATSR, and Passive Microwave Satellite Data: Algorithm Development and Application

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YEARS 2 AND 3 PLANS

Jeff Key
James Maslanik
Konrad Steffen

Cooperative Institute for Research in Environmental Sciences
University of Colorado at Boulder

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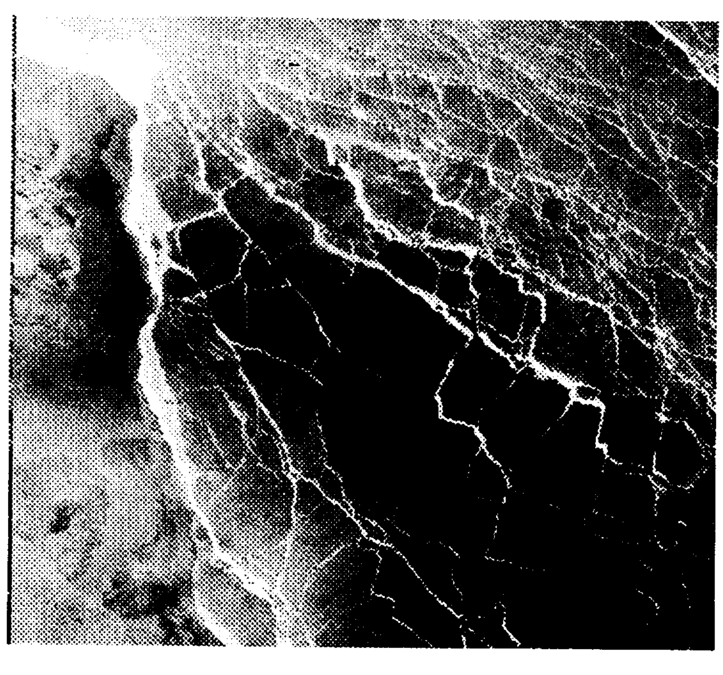
ATSR Brightness Temperatures, Beaufort Sea



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INTRODUCTION

One essential parameter used in the estimation of radiative and turbulent heat fluxes from satellite data is surface temperature. Sea and land surface temperature (SST and LST) retrieval algorithms that utilize the thermal infrared portion of the spectrum have been developed, with the degree of success dependent primarily upon the variability of the surface and atmospheric characteristics. However, little effort has been directed to the retrieval of the sea ice surface temperature (IST) in the Arctic and Antarctic pack ice or the ice sheet surface temperature over Antarctica and Greenland. The reason is not one of methodology, but rather our limited knowledge of atmospheric temperature, humidity, and aerosol vertical, spatial and temporal distributions, the microphysical properties of polar clouds, and the spectral characteristics of snow, ice, and water surfaces. Over the open ocean the surface is warm, dark, and relatively homogeneous. This makes SST retrieval, including cloud clearing, a fairly straightforward task. Over the ice, however, the surface within a single satellite pixel is likely to be highly heterogeneous, a mixture of ice of various thicknesses, open water, and snow cover in the case of sea ice. Additionally, the Arctic is cloudy - very cloudy - with typical cloud cover amounts ranging from 60-90%. There are few observations of cloud cover amounts over Antarctica.

The goal of this research is to increase our knowledge of surface temperaturepatterns and magnitudes in both polar regions, by examining existing data and improving our ability to use satellite data as a monitoring tool. Four instruments are of interest in this study: the AVHRR, ATSR, SMMR, and SSM/I. Our objectives are to

1. Refine the existing AVHRR retrieval algorithm defined in *Key and Haefliger* (1992; hereafter KH92) and applied elsewhere. While the algorithm is correct for the conditions stated in KH92, it may not be widely applicable to situations where there is extensive melt ponding or aerosol loading, for example. Climatological values with regional and temporal dependencies may be added. The possibility of a two-direction look at a given point (different scan angles from overlapping swaths) will also be investigated. Atmospheric corrections presented in KH92 are for NOAA satellites 7, 9, and 11. Additional corrections will be developed for NOAAs 8, 10, and 12. Comparisons of the empirical correction algorithm with one which utilizes TOVS sounder data on a pixel-by-pixel basis will be investigated.
2. Develop a method for IST retrieval from ATSR data similar to the one used for SST. This instrument provides two looks at the same scene and is designed for SST retrieval. Modeling studies analogous to those done with the AVHRR will be done for the ATSR.
3. Further investigate the possibility of estimating surface temperature from passive microwave data (in conjunction with AVHRR clear sky samples) through the use of "effective emissivities" (*Maslanik and Key*, 1993; hereafter MK93) and physical relationships between skin temperature and subsurface temperature. The pilot study described in MK93 needs to be expanded to include other regions and seasons. Error analyses of the uncertainties in atmospheric effects, surface emissivities, and ice concentrations are needed.

4. Use the general method outlined in MK93 to calculate a 12-year record of clear sky equivalent surface temperatures, or possibly all-sky snow-ice interface physical temperatures, from SMMR and SSM/I, compare these temperatures to climatologies, ECMWF modeled surface temperatures, and surface temperatures predicted by a 2-D ice model. The passive microwave-derived temperatures will be used to drive the ice model and the effects on the resulting ice pack will be observed. The ice model currently generates temperatures that appear high - we may find that use of the derived temperatures yield an unrealistic simulation of ice thickness, which in turn might allow us to pinpoint other shortcomings of the ice models.
5. Intercompare several ice surface retrieval methods and validate them against ground measurements from the Swiss Camp on the Greenland ice sheet.

Additionally, we intend to develop a surface temperature product based on AVHRR data and possibly blended with drifting buoy and meteorological station temperatures. However, the temporal coverage of this product will depend upon the availability of data from the Pathfinder activity. Discussions are underway with scientists from a number of agencies/institutes to coordinate our activities.

This document summarizes our progress to date, at the end of the first year, and lists our plans for the second and third years.

PART I: PROGRESS

1.0 Progress to Date: Data Acquisition

1.1 Satellite Data

1.1.1 AVHRR Coverage

The development and testing of the AVHRR IST algorithms and the SSM/I algorithms that use AVHRR data require a large sample of AVHRR coverage. To provide this, we have assembled AVHRR images from the NRL Leads image set (including 6 individual merged subsets of AVHRR and SSM/I), imagery covering the Seasonal Sea Ice Monitoring and Modeling Site (SIMMS) near Resolute Bay (the site of field measurements during spring of 1992 and 1993), daily imagery for the Beaufort Sea for June 1992 to July 1993 (acquired and processed as part of a separate NASA grant for ice motion studies from AVHRR), the Scripps archive for the Antarctic that is currently available from NSIDC, and 44 AVHRR LAC scenes of the Greenland ice sheet for mid-May through the end of June 1993. This latter set has not yet been georeferenced and calibrated. In addition to these existing images, the Domsat receiving station operated by the Colorado Center for Astrodynamics Research will come on-line soon. The Domsat will provide a constant stream of AVHRR coverage that will be particularly valuable for the large-scale coverage required by the SSM/I IST algorithms in development.

Product generation will, however, utilize other AVHRR data sets. GAC data from 1984 are being processed for the IST sampler (see Section 3.1) while we await four months of data from the AVHRR Pathfinder Activity. Data to be used to generate the final product will most likely also come from Pathfinder.

1.1.2 SSM/I Coverage

In addition to SSM/I data on CD-ROM, we have acquired orbital SSM/I data from the Canadian Atmospheric Environment Service to cover the SIMMS field site in 1992 and 1993. Additional coverage for the field site have also been extracted from orbital data using the NSIDC's EZ-GRID system. To provide coincident data with the 1992-93 AVHRR coverage for the Beaufort, the Wentz data were obtained on digital tape from NSIDC and are bing processed at CCAR.

1.1.3 ATSR

ATSR data are being acquired for algorithm validation purposes only. Data are being obtained directly from Rutherford Appleton Laboratory (England) for times and locations corresponding to recent field experiments. Coverage of one month or more is being pro-

vided (to J. Key) for the following experiments/locations: LEADEX (March 1992, Beaufort Sea), SIMMS'92 (April-May, 1992, Canadian Archipelago), the Weddell Sea (July 1992), the Greenland Sea (February 1992), and Greenland (August 1991, March and July 1992). To date approximately 80 Exabyte (8 mm) tapes with images covering all of these areas have been received. Figure 1 gives an example of the ATSR 11 μm channel brightness temperatures of the Beaufort Sea and the North Slope of Alaska.

Fig. 1. ATSR channel 1 (11 μm) brightness temperatures of the Beaufort Sea and the coast of Alaska (lower left).

1.2 In-Situ Data

1.2.1 Arctic Soundings

Clear-sky (less than 25% cloud cover) temperature and humidity profiles collected on a Soviet ice island (NP-26) located at approximately 85^{O}N, 170^{O}W during 1986-1987 were used to prescribe typical conditions in the central Arctic in the original KH92 algorithm (KH92; *Serreze et al.*, 1992). We have expanded the geographic coverage of the rawinsonde data to include the entire Arctic. All data are currently in-hand. Figure 2 shows all available stations (approximately 1.6 million soundings), a temporal subset of which is being used in this study.

1.2.2 Antarctic Soundings

For the Antarctic, radiosonde profiles for a number of stations around the Antarctic continent have been collected by the British Antarctic Survey for 1981-84 and 1989-91. These

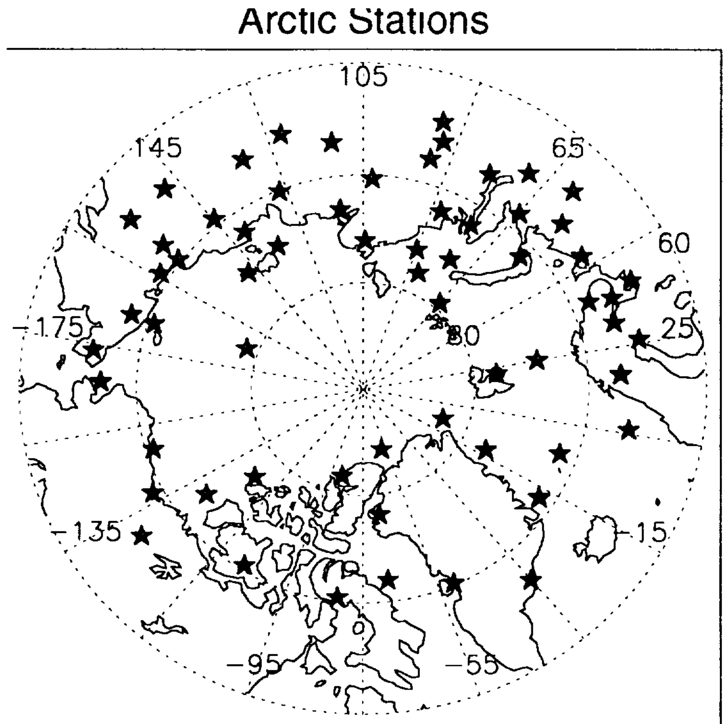

Fig. 2. Arctic stations for which radiosonde data are available. A subset of these stations will be used in the radiative transfer modeling of AVHRR radiances.

data have been provided to us by Dr. J. King of that institute (c.f., *Connolley and King*, 1993). Figure 3 shows the locations of the Antarctic stations for which radiosonde profiles have been collected. Figure 4 shows the mean December temperature profiles from three of those stations.

1.2.3 Drifting Buoys, NMC, Modeled Fields

Temperatures from the Arctic Drifting Buoy Program are available to overlapping portions of the AVHRR and SSM/I data sets. These have been acquired from NSIDC and the University of Washington. Although the drifting buoy temperatures from the early spherical buoys must be treated with caution (R. Colony, pers. comm.), they still can provide a useful comparison to other data sets, including microwave data (e.g., *Comiso*, 1983; *Maslanik and Barry*, 1989). We have also obtained NMC and ECMWF gridded surface air temperatures from the National Center for Atmospheric Research.

Ice surface temperature grids have been generated using a 2-D ice model. These data will be used for comparison to remotely-sensed IST.

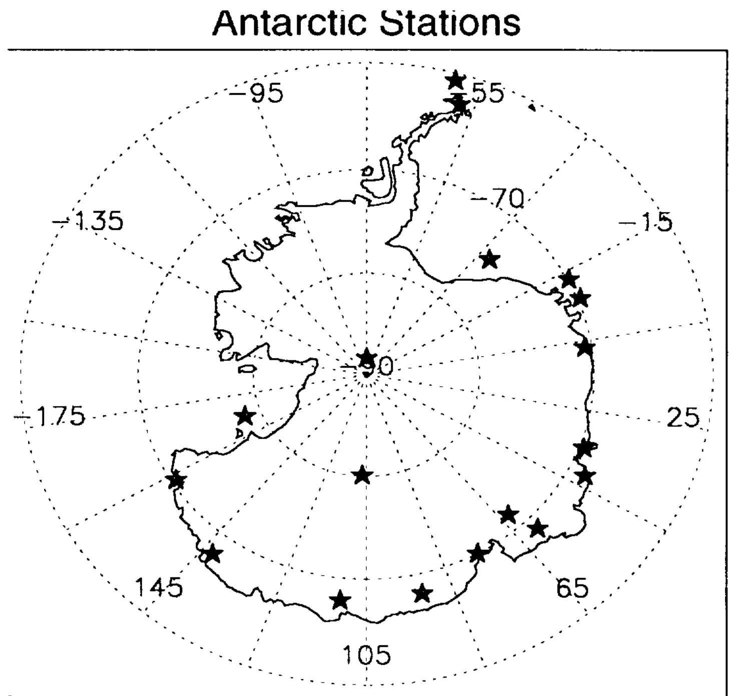

Fig. 3. Antarctic stations for which rawindonde data are in-hand. Data from these stations will be used in the IST modeling studies.

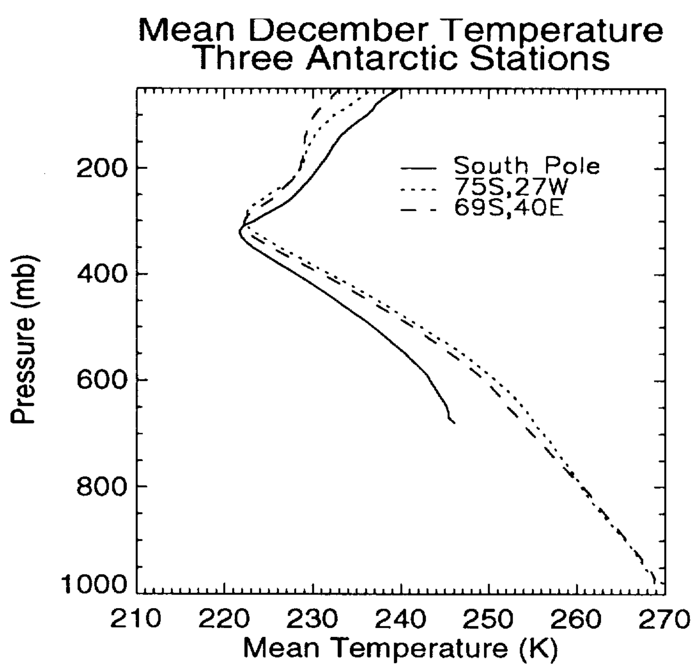

Fig. 4. Mean December temperature profiles for three Antarctic stations: the South Pole and two coastal stations.

1.2.4 Field Experiments

Snow and ice surface temperatures were recorded during several field campaigns at the Swiss Camp (69^{o}34' 25" N, 49^{o}17' 44" W) on the Grrenland ice sheet. This ground truth site is ideal for algorithm validation and intercomparison because of the homogeneous surface with a slope of less than 2^{o}, atmospheric information from radiosonde profiling, and low cloud amount (<30%) during spring.

Air temperatures, skin temperatures, and snow/ice interface temperatures acquired at the SIMMS site during May-June 1992 and 1993 are available for comparison to the AVHRR and SSM/I data. Surface measurements collected during LEADEX have also been processed.

2.0 PROGRESS TO DATE: METHODS

2.1 Estimates of IST Using Thermal Data

2.1.1 Thermal Emissivities of Snow

The surface emissivity originally used in KH92 was based on a two-stream model of the transfer of radiation through snow. Very recently, however, what may be the first laboratory measurements of the emissivity of snow have been made by a member of EOS's ASTER instrument team (J. Salisbury, pers. comm., 1993). There are minor differences between the observed and modeled emissivities for independent grains, but potentially large differences when grains weld together, as they do during summer. The laboratory measurements have been provided to the investigators of this project and are being used in conjunction with modeled snow and water emissivities to derive more realistic summer values than were used in KH92. These emissivities better represent a mixture of large-grain snow, melt ponds, and open water. They are being used during June-August in the Arctic and December-February for Antarctic coastal stations.

2.1.2 Radiance Simulations

AVHRR radiance simulations using the LOWTRAN-7 radiative transfer model have been completed using the newly-acquired Arctic and Antarctic radiosonde data and emissivity measurements. The form of the surface temperature predictive equation will change slightly, in order to be more consistent with that used in sea surface temperature retrievals. Sensitivity studies concerning the effects of spring aerosol loading, surface melt, and geographic variations in total precipitable water are in progress.

Because of the similarity of AVHRR and ATSR thermal channels, the radiance simulations done for the AVHRR will also be used for the ATSR. However, we have been delayed somewhat as a result of the difficulty in obtaining response function information from ESA or RAL. A new contact in RAL promises that this situation will soon be resolved. When response function data are available, we can quickly develop our own atmospheric

correction coefficients, and will compare our retrievals to those of RAL with the ATSR validation data that is currently in-hand.

2.1.3 Ice Model Modifications

We have modified our current ice model to generate daily surface temperatures using an energy balance scheme driven by climatological and daily air temperatures with parameterized radiation and oceanic heat flux. Given the uncertainties in variables such as cloud cover, air temperatures, and winds, we do not expect a match between remotely-sensed IST and the modeled IST. However, by comparing the two IST fields, we will be able to identify any large differences that might indicate significant model errors.

2.1.4 Cloud Clearing in AVHRR

Cloud detection in satellite data is the largest obstacle in the path of accurate surface temperature estimation, and is most difficult in the polar regions where surface temperatures and reflectances are often very similar to those of the cloud tops. Cloud detection and analysis research is in progress by the PI under separate funding (EOS-POLES), where a radiative transfer model is being used to determine under what types of atmospheric and surface conditions clouds can be detected in AVHRR data. These modeling results will help assess the probable errors in IST estimates.

2.2 Estimates of IST Using Passive Microwave Data

Building upon our earlier work to estimate IST from passive microwave data, we have begun three separate analyses, which will be followed by additional experiments as SSM/I data become available. Some results of these current analyses are summarized below.

2.2.1 Passive Microwave Ice-Surface Temperatures - Error Analyses

To determine the utility of passive microwave data for ice temperature estimates, we have begun by assessing the ranges of errors likely from three factors: (1) atmospheric conditions; (2) uncertainties in emissivities and ice concentrations; and (3) effects due to differences in the depth of the emitting layer versus the desired surface temperature.

Work to date has focused on describing the contributions of atmospheric water vapor, cloud liquid water, cloud type, and cloud height on the top-of-the-atmosphere brightness temperatures. Sensitivity experiments have been performed using the RADTRAN radiative transfer model for microwave regions. Results show that atmospheric contributions are significant, depending on cloud type and conditions. For example, over open water, a stratus cloud layer can increase brightness temperatures by 18 K at 19 GHz H, and 11 K at 19 GHz V., with increasing effects at the higher frequenciies. Atmospheric conditions can therefore have a substantial effect on surface temperatures retrieved from brightness temperatures at individual channels. RADTRAN's performance appears to be poor at high frequencies, and yielded unrealistic numbers at 37 GHz. We plan to test a different atmospheric radiative transfer model for application at 37 and 85 GHz. Our next steps are to

refine these atmospheric sensitivity studies, and determine whether the main potential advantage of SSM/I for surface temperatures - its ability to detect temperatures beneath clouds - is negated by atmospheric emission.

2.2.2 Comparison of SSM/I Brightness Temperatures to Field Observations

The objective of this step is to compare SSM/I brightness temperatures (TB) and SSM/I-derived IST to surface measurements of skin temperature, snow/ice interface temperature, surface air temperatures, and surface conditions. The source for the field data are the 1992 and 1993 SIMMS project noted earlier. Currently, we have compared data for late April and early May, 1992, and early May 1993. For the 1993 data, IST has been estimated from orbital SSM/I data using an emissivity-based algorithm, e.g.,

$$IST = \frac{T_B - e_w T_w C_w}{e_f C_f + e_m C_m}$$

where e_w, e_f, and e_m are emissivities of water, first-year ice, and multiyear ice at the given frequency, T_w is the physical temperature of open water (taken to be 273.16 K), and C_w, C_f, and C_m are the concentrations of open water, first-year ice, and multiyear ice as estimated using the NASA Team algorithm. Emissivities are taken from the literature. IST was also calculated assuming 100% first-year ice in the field of view. The resulting SSMI-derived ISTs at 19 GHz and 37 GHz vertical polarization were compared to surface measurements.

Overall, the emissivities used appear to be too low, yielding mean surface temperatures for 1-8 May 1993 of 272.8 K at 19 GHz and 270.7 K at 37 GHz, compared to measured skin temperatures of approximately 253 K for the period. Snow/ice interface temperatures average about 2 K warmer than the skin temperatures, consistent with the warmer temperatures at 19 GHz which, with likely emanate from near the snow/ice interface. Based on the observed surface temperatures, the 19V and 37V emissivities were 0.97 and 0.93, compared to the literature values used of 0.95 and 0.94 for first-year ice. Some error is also introduced by the ice classification, which yielded a total ice concentration of about 93% with a 20% proportion of multi-year ice. Actual conditions at the field site were 100% concentration, with only a small amount of multi-year ice. Assuming 100% concentration of first-year ice, the simple conversion of TB to IST using emissivity in the Stefan-Boltzman relationship yields 19V IST of 257 K and 37V IST of 253 K. In this case, knowledge of the true surface ice type distribution allows a reasonable estimate of IST, while the ice type dependent IST algorithm yields greater errors due to the misclassification of the surface ice types.

Alternatively, if the approximate surface temperature is known (from AVHRR, for example or, in this case, from the field observations), then we can constrain the ice concentration algorithm to yield realistic ice type mixtures given an approximate physical temperature and emissivities. For example, from the SIMMS case, a 100% cover of

first-year ice is in fact the best ice type classification to yield the observed temperatures. We are considering whether an iterative process that combines AVHRR and SSM/I might be used to arrive at an optimal solution of temperatures and ice type mixtures.

2.2.3 Spatial distributions of SSM/I and AVHRR IST in the Arctic

In this comparison, we are currently examining six sets of co-registered AVHRR and SSM/I images in September 1991 and March 1992. These include images in the Beaufort, Chukchi, and Greenland seas. SSM/I data have been classified using the Team algorithm. The AVHRR data are calibrated to physical temperature but have not yet been processed to remove atmospheric effects. The SSM/I data are converted to IST using the ice type-dependent algorithm given in the previous section, and compared to the AVHRR temperatures. In our current results, we find substantial differences between the SSM/I and AVHRR ISTs. For example, using the SSM/I IST algorithm described above, we find one case where a paired AVHRR and SSM/I image set for March 1989 yields AVHRR ISTs of approximately 248 K, while the SSM/I ISTs at 19V are 285 K. IST at 37V is about 11 K cooler and perhaps more indicative of near-surface temperatures. Since these AVHRR ISTs are not corrected for atmospheric effects, perhaps a 2 to 3 degree error exists in the AVHRR values. Clearly though, the SSM/I ice type classification and/or the assumed emissivities are in error. The best fit with the AVHRR ISTs is found by assuming a 100% ice cover of first-year ice. Given the time of year and region (southern edge of the Chukchi Sea, this ice distribution may be more realistic than the Team algorithm results of 68% first-year ice, 21% multi-year ice, and 11% open water.

Using these data sets, we also plan to test the approach we developed earlier, in which AVHRR ISTs are used to "calibrate" the SSM/I temperatures, with the SSM/I then used to estimate temperatures in areas for which AVHRR coverage is not available.

2.3 Sea-ice Modeling

A 2-D dynamic-thermodynamic ice model for the Arctic has been modified to accept input surface temperature fields in lieu of the existing energy balance calculation. This model is essentially the same as that currently used in the NCAR Genesis earth-systems model. We plan to use the ice model as a test-bed for assessing the effects of errors in the IST field, and for determining improvements resulting from the inclusion of observed temperatures. These results may then be applied directly to the ice model in the GCM.

3.0 PROGRESS TO DATE: PRODUCT GENERATION

3.1 AVHRR-based IST Sampler

A sample IST product is being prepared using AVHRR data and should be completed in the first quarter of Year 2. Due to unforeseen circumstances regarding data acquisition and processing we are using GAC data for two weeks in both January and June 1984 (data currently available from CCAR, CU) to develop the multi-level processing procedure that starts with AVHRR Level 1B and ends with a 5-day AVHRR clear sky surface temperature

product, as described below. We await the delivery of 2-4 months of data from the AVHRR Pathfinder Activity. However, product generation will proceed on the CCAR data.

Two methods of surface temperature product generation are being explored. Dr. J. Comiso (NASA GSFC) will compute surface temperatures directly from the ungridded AVHRR data. Those temperatures will then be gridded and averaged over space and time as deemed appropriate. We will compute surface temperatures from a higher-level AVHRR product with the following features:

- **Spatial coverage**: Arctic and Antarctic, poleward of 55 degrees latitude.
- **Temporal coverage**: January and July, 1984.
- **Grid**: polar stereographic, the SSM/I grid. If comparisons with SSM/I data are desired, the EASE grid can be used with the same projection as the SSM/I grid.
- **Spatial resolution**: GAC.
- **Channels**: All 5 spectral channels, plus sensor scan (or zenith) angle, solar zenith angle, the relative azimuth angle between the satellite and the sun. All these data stored in 16 bits. There will be "images" of latitude and longitude, also 16 bits each, and a coastline image (8 bits).
- **Spatial and temporal sampling**: If there are multiple pixel choices for a given grid cell the following scheme will be followed. Suppose, for example, that for the 12Z, 5 January 1988 grid at some location there is one observation with a time of 1215 at a scan angle of 30 degrees, and another at a time of 1230 and a scan angle of 20 degrees. Consider a time/space weighting function of this nature:

  $d = (delta\text{-}time * mu1 * w1) + (angle * mu2 * w2)$

  where *delta-time* is the time difference in minutes between the target time and the pixel time, angle is the scan angle in degrees, *mu1* and *mu2* are normalizing factors, and *w1* and *w2* are weights. For example, let $mu1 = 1/60$, $mu2 = 1/30$, $w1 = 0.7$, and $w2 = 0.3$. Then for the first case (time=1215 and *angle*=30), *d*=0.475, and for the second case (time=1230 and *angle*=20), *d*=0.550. The first case is selected since it's "distance" from the target (12Z at nadir view) is the smallest. Note that these values of *mu1* and *mu2* produce the same approximate range for the time and angle distances for a +-2 hour cutoff and the 0-55 degree AVHRR scan angle range; e.g., *delta-time*mu1* is in the range [0,2] as is *angle*mu2* (approximately).
- **Quantization**: Channels 3-5: brightness temperatures in the range of 100-350K, with a precision of 0.01K. Since values in the range of approximately -16,000 to +16,000 can be stored in a 2-byte integer, then assign a temperature of 225K to a count of 0 and have each count equal 0.01K; e.g., 225.00K=0, 225.01K=1, 224.99K=-1, 350K=12,500, 100K=-12,500. So, the stored value, *N*, is:

  $N = \mathrm{nint}((Tb - 225.0) * 100.0)$

  Channels 1-2: albedos in the range of 0-100 with a precision of 0.01.

The characteristics of our surface temperature sample product are:

- **Spatial coverage**: Arctic and Antarctic, poleward of 55 degrees latitude.
- **Temporal coverage**: January and June, 1984.
- **Grid**: polar stereographic, the SSM/I grid.
- **Temporal resolution**: Two times per day, 0Z and 12Z, though due to cloud cover a 5-day composite (still at two times per day) will probably be compiled.
- **Spatial resolution**: GAC for the sample product.

3.2 Interannual Variability of SSM/I-derived IST

The objective of this task is to generate a multi-year time series of IST using SSM/I data alone. Data and procedures are currently in hand to do this. However, as noted in the comparison of SSM/I and field data, more work needs to be done to define the value of the SSM/I-only ISTs. Ultimately, we hope to generate these Arctic-wide coverages, and then substitute these ISTs for the simulated ISTs in our sea ice model. We can then determine whether the other components of the model continue to generate reasonable ice-thickness fields, with the potential of providing more spatial detail on ice growth and decay than is possible using the current atmospheric forcings that drive the model.

3.3 Blended *In Situ* Product

The goal of this task is to produce a surface (or near-surface air) temperature product from existing *in situ* data. In the both polar regions these data are from meteorological stations (Figures 5 and 6), but in the Arctic they will also consist of temperatures measured by drifting buoys. The buoys will provide more complete spatial coverage of the central Arctic while the meteorological stations provide temperatures for the coastal areas.

All data have been acquired during Year 1. Methods of combining the data will be developed and the product will be generated during Year 2.

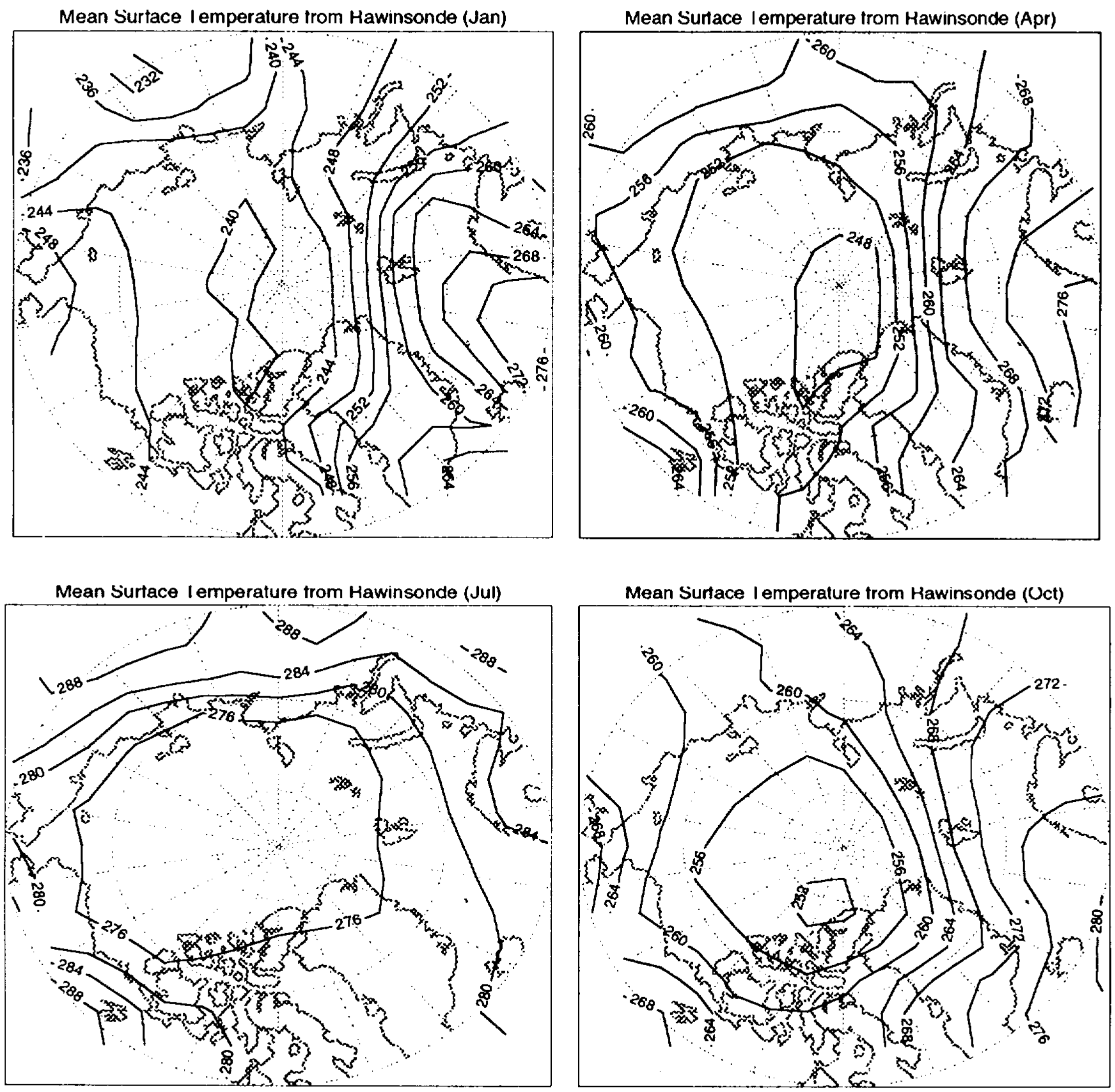

Fig. 5. Mean near-surface air temperature in the Arctic for the months of January, April, July and October based on rawinsonde observations.

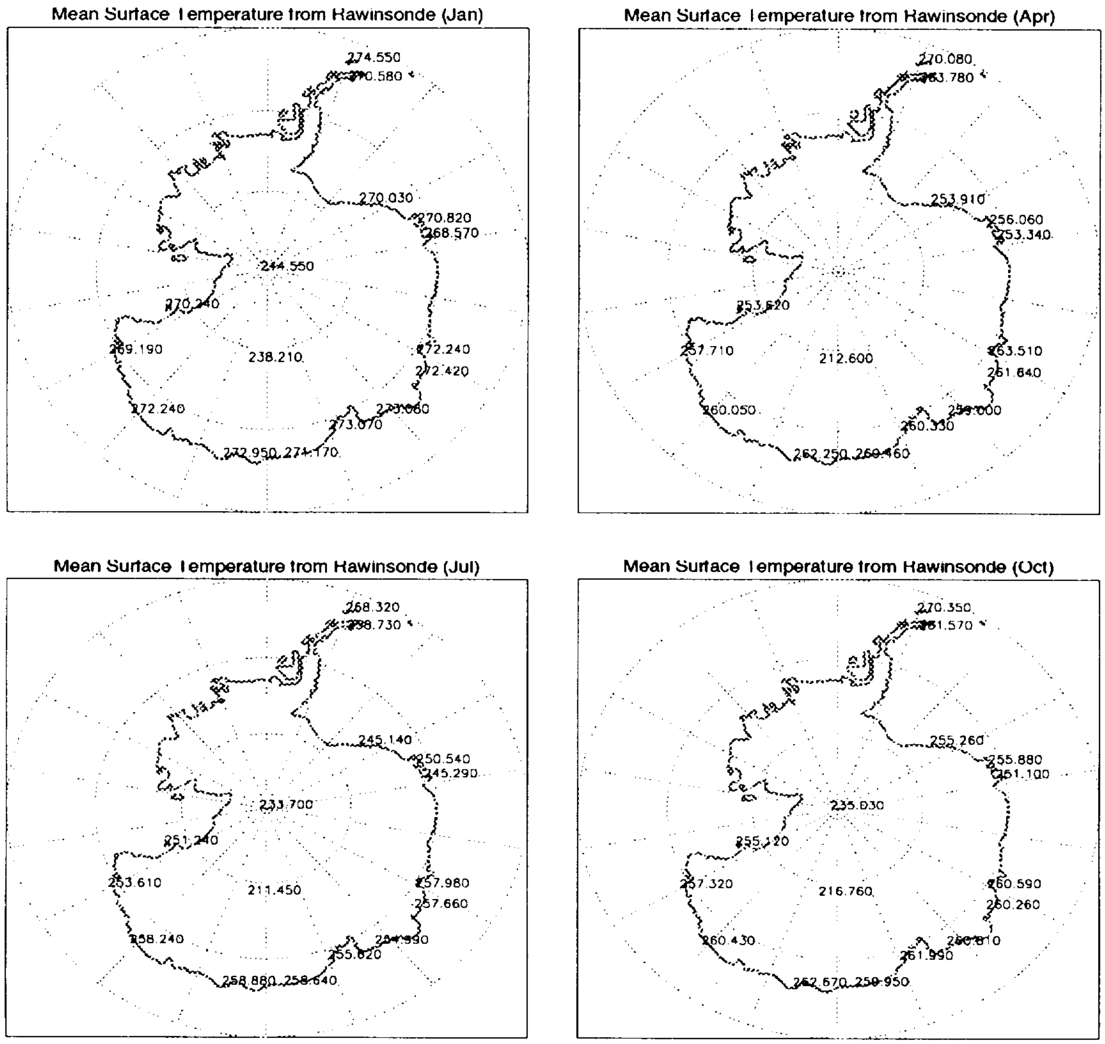

Fig. 6. Mean near-surface air temperature in the Antarctic for the months of January, April, July and October based on radiosonde observations.

3.4 Blended AVHRR-*In Situ* IST Product

While one of our original objectives was to generate a clear-sky ice surface temperature product from AVHRR data, this goal has been modified somewhat as a result of discussions that took place at the Workshop on Polar Data Sets, Seattle (October 1993). A blended product based on AVHRR clear-sky and drifting buoy temperatures generated considerable interest. Whether or not other data sources can be incorportated - e.g., TOVS or SSM/I - is yet to be determined.

The detailed structure of the blended product is uncertain at present, although it will be similar to the sample AVHRR product discussed previously. Its temporal coverage will depend upon the availability of data (probably from the Pathfinder activity) as well as funding for data processing since this was not part of our original budget. We do not anticipate the need for additional funding to blend the buoy and AVHRR temperatures, although the elimination of one or more subtasks may be required.

4.0 COLLABORATIVE EFFORTS

Dr. Comiso (NASA GSFC) will be involved primarily in algorithm development for the Antarctic, using AVHRR data and in situ observations directly, and will also play a role in the Arctic work and will consult with J. Maslanik on the passive microwave algorithm development. Due to unforeseen circumstances the AVHRR data processing will be done here at CU. Because of their experience in this area, personnel at CCAR have been enlisted to aid in this processing. A graduate student will perform most of the programming tasks with guidance from D. Baldwin and C. Fowler of CCAR.

Per Gloersen (NASA GSFC) will be involved in ongoing discussions concerning the passive microwave ice temperature product. He has considerable experience in ice temperature estimation using SMMR. Frank Carsey (JPL) has been consulted concerning validation of ATSR-derived surface temperatures in the Weddell Sea. Roger Colony (University of Washington) will be involved in the blending of buoy and AVHRR-derived temperatures, although the level of his involvement is unclear at this time

Bill Rossow (NASA GISS) of the ISCCP has been investigating surface temperature retrieval over the ice-free ocean using a radiative transfer model on a pixel-by-pixel basis. This methodology was also suggested in our original proposal. Therefore, we will work with him on this aspect of the project. Additionally, the ISCCP will generate an AVHRR product that may - depending on its characteristics - be used for our final surface temperature product generation.

This project also has a symbiotic relationship with three other NASA-funded projects: POLES (D. Rothrock, University of Washington), the EOS NCAR project to interface observations with global modeling (R. Dickinson, University of Arizona) and K. Steffen's Greenland project. In particular these projects are providing validation data and efforts for methods developed here.

5.0 PUBLICATIONS SUPPORTED IN WHOLE OR IN PART BY THIS GRANT

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PART II: YEARS 2 AND 3

Up to this point, a preliminary set of refined AVHRR IST retrieval coefficients has been computed, and ATSR modeling has begun. The coefficients are termed "preliminary" because a finalized cloud clearing algorithm is not expected to be available until the middle of 1994, and because all sensitivity tests originally proposed will not be complete. However, the AVHRR-based IST sampler is expected to be available for examination very soon. Passive microwave studies of atmospheric effects and the estimation of sea ice emissivities have begun.

1.0 YEAR 2 PLANS

During Year 2 we will continue studies of the sensitivity of AVHRR and ATSR-derived IST estimates to atmospheric water vapor, aerosols, and surface conditions. Boundary layer modeling studies of the change in surface temperature under cloud cover (for AVHRR applications) will begin. Methods of blending AVHRR and buoy temperatures will be investigated and spatial and temporal covariances from both data sets will be computed. Passive microwave modeling studies and algorithm development will continue. All algorithms are expected to be near completion and all product specifications made by the end of our second project year. The overall utility of using passive microwave data for surface temperature estimation will be assessed.

Algorithm validation will be done with ATSR, AVHRR and SSM/I data collected for the field experiments described earlier; e.g., for the Swiss Camp on the Greenland ice sheet, SIMMS, and LEADEX.

2.0 YEAR 3 PLANS

The focus of Year 3 will be product generation and application. A blended ice (sea and land) surface temperature product for both polar regions will be generated. The exact period of record will, however, depend upon data availability. Ideally we (with J. Comiso) would produce a 10+ year record of surface temperature in the polar regions. This will actually be two products: an AVHRR-derived clear-sky surface temperature and the all-sky AVHRR/buoy blended product. Because the blended product will be neither skin temperature or near-surface air temperature but rather a combination of the two, the clear-sky only skin temperatures may be preferred for certain applications.

If judged to be worthwhile, a 12-year time series of "surface" temperature from SMMR and SSM/I will also be produced starting in the latter half of Year 2. At present it has not been determined if this product should be a "clear-sky equivalent" skin temperature, as described earlier, or a snow-ice interface (approximately) physical temperature similar to what has been done by Per Gloersen with SMMR. In any case, clear sky AVHRR data will be used to estimate the emissivity of the sea ice.

After these products are generated they will be used as forcing fields in a two-dimensional dynamic-thermodynamic sea ice model. Time-permitting (research time and NCAR computing time), they will also be used in a GCM, either directly as ISTs, or indirectly by incorporating improved physics into the GCM based on results achieved using the ice-only model. We also hope to improve the value of the ice modeling integration by coupling the ice model to the GFDL ocean model under separate funding.

3.0 PRODUCT SCHEDULE

By the end of each project year we expect to produce the following data sets:

Year 1, First Quarter Year 2
IST Sampler. A clear-sky AVHRR-derived sample surface temperature product.

Year 2
(1) Blended *In Situ* Sampler. A blend of temperatures from drifting buoys and meteorological stations
(2) Blended AVHRR/Buoy Sampler. The IST Sampler blended with drifting buoy temperatures.
(3) SSM/I Sampler. Either snow-ice interface physical temperatures or the "clear-sky equivalent" skin temperatures based on SSM/I and AVHRR data.

Year 3
The geophysical variables will be the same as those produced in Years 1 and 2, but will have much greater temporal coverage, probably on the order of 5-8 years.